MUNICIPAL WASTEWATER RENOVATION, GROWTH AND NUTRIENT UPTAKE IN AN IMMATURE CONIFER-HARDWOOD PLANTATION [1]

D. G. Brockway, G. Schneider, and D. P. White [2]

INTRODUCTION

The impact of wastewater applications upon a variety of forest ecosystems has received widespread attention in the United States over the past 20 years. During this period the efforts of many researchers have improved our understanding of the species composition and site characteristics which are appropriate for wastewater irrigation in various forest types (Smith and Evans 1977). A 1977 symposium sponsored by Pennsylvania State University treated the topic of wastewater discharge effects upon various sites. Sixteen papers dealt specifically with research conducted on forestlands (Sopper (Ed.), In press).

When tree plantations are established upon "old field" sites, plants in the well developed Ap horizon frequently compete vigorously with the newly planted seedlings for water and nutrients. Cultural treatments, such as wastewater irrigation, which supplement supplies of water and nutrients, greatly enhance seedling survival and plantation growth if competition from weeds is controlled. This is especially true for hardwood seedlings which are often less tolerant than conifers in competing with grasses and associated vegetation.

In 1974, three conifer and seven hardwood species were planted in an old field and irrigated with municipal wastewater. Objectives were (1) to

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[2] The authors are, respectively, Research Forester, North Central Forest Experiment Station, USFS, East Lansing, Michigan; Professor and Head, Department of Forestry, Wildlife and Fisheries, University of Tennessee Knoxville, and Professor Department of Forestry, Michigan State University, East Lansing, Michigan.

determine the site's ability to renovate applied wastewater and thus provide a high quality groundwater recharge and (2) through monitoring seeding growth and nutrient uptake, to assess each tree species' suitability for plantation establishment on old field sites under wastewater irrigation. Site responses to wastewater applications are described over four growing seasons, 1974 to 1977.

MATERIALS AND METHODS

Detailed establishment procedures and a site description for the 2.1 ha old field study area were reported earlier (Brockway et al.1978). The site is located 5 km south of the main campus of Michigan State University (M.S.U.) at East Lansing, Michigan. Gently rolling glacial till, 20 m deep, overlies a bedrock of Saginaw sandstone. Previously farmed, the area originally supported a beech-maple forest.

A well developed sod and herbaceous layer, including *Solidago*, *Digitaria*, *Agropyron* and *Andropogon* existed in 1974. The Miami-Conover-Brookston Alfisol soil catena dominates the site. Annual precipitation averages 765 mm (30 in.). Secondary sewage effluent obtained from the East Lansing Municipal Waste Treatment Facility is cycled through a system of four ponds ranging in size from 3 to 5 ha. Water from the first pond, highest in nutrient content, was delivered to the study site via an overhead spray irrigation system consisting of 39 Buchner #8600 sprayheads spaced 25 m x 30 m.

The plantation was established in April 1974, following a pre-planting weed control treatment consisting of a herbicide mix of paraquat-CL (1.1 kg/ha) and simazine (2.2 kg/ha). Tree rows in all plots were chemically weeded annually using glyphosate (1.4 kg/ha). Weeds between rows were mowed semi-annually and irrigation lines were kept clean with a simazine-atrazine treatment. The 10 tree species planted were American sycamore (*Platanus occidentalis* L.), black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), eastern cottonwood (*Populus deltoides* Bartr.), northern red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), tulip poplar (*Liriodendron tulipifera* L.), Scotch pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* Karst.), and white spruce (*Picea glauca* Voss.). Since 1976, trees have been side pruned and basal sprouts removed to encourage single stem development.

The experimental design consists of 14 randomized complete blocks (replications). Each block contains 10 species organized into 10 rows, each 62.8 m (200 ft) long and containing 40 individual trees of a single species, totaling 5600 seedlings in the entire plantation. Spacing is 1.5 m x 2.1 m (5 ft x 7 ft), with each block delineated by intervening irrigation lines. Replication 1 was the control plot, receiving no irrigation, while replications 2 through 14 were treated with 51 mm of effluent per week, for approximately 15 weeks each season.

Samples of irrigation water from the sprayheads were taken weekly in 1975 and 1976 and monthly in 1977. Throughout the study, percolating water samples were obtained weekly with 15 suction lysimeters placed 61 cm deep and evacuated to 33 cm of Hg; their location was stratified by soil type, topography and treatment. Water sample pH was recorded using a glass electrode.

Samples were preserved using concentrated sulphuric acid (1 ml/600 ml) or concentrated nitric acid (1 ml/300 ml) depending upon the ionic species for which analysis was desired. Water samples were placed in cold storage until analysis could be conducted at M.S.U. and the University of Wisconsin.

Soil samples were collected in May and September 1975, in September of 1976 and October of 1977 at depths of 0-15, 15-30, 45-60, and 105-120 cm. Sampling was conducted in systematic fashion so as to obtain samples of the four depths at each of 36 loci at evenly spaced intervals across the plantation. Soil samples were air dried, composited by soil type and depth, pulverized and passed through a 2 mm screen. Soil nutrient analyses were performed by the M.S.U. Soil Chemistry Laboratory and A & L Agricultural Laboratories of Fort Wayne, Indiana.

Assessment of tree growth and nutrient status was made in September of 1975, 1976 and 1977 following each irrigation season. Foliar samples were taken from all trees in replications 1 through 10 and composited by row. One representative tree was selected from each sampled row and cut at groundline. Total height and basal stem diameter were recorded in the field. Oven dry weights (75°C) of the total tree, foliage and stem components were determined. Foliar samples from each row were ground in a Wiley mill and passed through a 20 mesh screen. Nitrogen was determined by the macroKjeldahl method. Potassium determinations were accomplished by water extraction and leachate analyzed by flame spectrophotometry. A mass spectrograph was used to determine foliar contents of boron, calcium, phosphorus, sodium, magnesium, manganese and zinc.

RESULTS AND DISCUSSION

Water Quality

Irrigation Volume: Wastewater volumes delivered during the growing seasons to the plantation site follow:

Growing Season	Irrigation (mm)
1974	216
1975	718
1976	815
1977	1,384

A systematic irrigation schedule was not fully operative until August 1974, resulting in the low level of water applied during the first year. The weekly irrigation level averaged 51 mm applied in at least two treatment periods, approximately 25.5 mm each. The application rate was approximately 4.2 mm/hr.

Groundwater Recharge: Groundwater recharge was computed using the method of Thornthwaite and Mather (1957) from weather data collected 2 km from the site. Of the 13 months examined over a 3-year period, rainfall exceeded

TABLE 1. THORNTHWAITE WATER BUDGET CALCULATIONS FOR WASTEWATER RENOVATION OF MICHIGAN STUDY SITE, 1975, 1976, AND 1977

	Adj. Monthly PE	Monthly Rainfall	Monthly Irrigation	Groundwater Recharge
	-mm-			
1975				
June	150	21	116	0
July	160	68	253	161
Aug.	132	180	264	312
Sept.	68	63	81	76
1976				
June	155	96	112	53
July	165	217	277	239
Aug.	119	11	252	144
Sept.	75	44	175	144
1977				
May	165	11	249	95
June	136	83	292	239
July	169	74	285	190
Aug.	127	69	285	227
Sept.	75	137	274	336

PE only during August 1975 and September 1977 (Table 1). In June 1975, there was no net groundwater recharge as PE exceeded total monthly precipitation, as is normal for this region. Groundwater recharge occurred in the remaining months as a result of irrigation.

Nutrient Loading: The major nutrient content of the effluent used in this study is similar in composition to that reported by Burton and Hook (1978) and is presented in Table 2. Effluent nitrate levels often approached or exceeded the 10 ppm U.S.E.P.A. interim drinking water standard.

TABLE 2. MEAN EFFLUENT CONCENTRATIONS OF MAJOR NUTRIENTS

Nutrient	1975	1976	1977
		ppm	
Total N	10.9	15.1	11.4
NO_3	6.6	10.9	7.4
NH_4	3.1	2.0	1.4
P	1.5	3.9	2.5

Total nitrogen loading ranged from 75 to 160 kg/ha/yr with NO_3 the predominating form (Table 3). Nitrate loading accounted for less than 100 kg/ha/yr of the total N. Ammonium effluent levels resulted in an NH_4 loading rate of less than 21 kg/ha/yr. Generally, N losses from the rooting zone remained small, never exceeding 31 kg/ha/yr. Losses of nutrients from the rooting zone were calculated using groundwater recharge values computed from precipitation and PE data and nutrient concentrations of soil percolate sampled at 61 cm.

Phosphorus loading rates ranged from 9 to 30 kg/ha/yr, and losses from the rooting zone were negligible. The higher Na loading rates have been implicated in degrading fine textured clay soils, but are not of great concern in this humid region. Loading and loss rates of other micronutrients were proportionally stable in the years examined.

Micronutrients supplied to the site were in all but one instance less than that which escaped the rooting zone. In 1975, effluent B levels were sufficient to result in a 5.5 kg/ha/ loading rate but thereafter the rate declined. The rate loss of micronutrients from the rooting zone is likely to be a function of the micronutrient concentrations found in the effluent. In time, the micronutrient levels in the percolate should reach a new equilibrium, given the constant input of the dilute micronutrient irrigation water.

Wastewater Renovation: Generally, the site is adequately renovating the the most troublesome nutrients, nitrate and phosphorus (Table 4). Nitrate

TABLE 3. MICHIGAN STUDY SITE NUTRIENT BALANCE SHEET FOR 1975-1977 GROWING SEASONS

Nutrients	1975		1976		1977	
	Nutrient Load With Irrigation	Nutrient Escape From Rooting Zone	Nutrient Load With Irrigation	Nutrient Escape From Rooting Zone	Nutrient Load With Irrigation	Nutrient Escape From Rooting Zone
	kg/ha					
NO_3	45.6	#	80.5	19.1	90.3	13.5
NH_4	20.4	#	19.8	4.8	16.7	9.1
Total N	74.7	#	116.7	30.4	159.7	26.0
P	9.1	0.5	30.0	0.6	30.3	0.6
K	175	55.8	78.7	+	128.8	44.9
Na	1706	487	709	245	1180	806
Ca	1409	761	615	290	732	621
Mg	625	286	210	108	322	271
B	5.5	1.6	0.5	1.2*	4.1	9.8*
Mn	2.1	35.5*	0.8	4.8*	0.8	11.9*
Zn	0.9	8.0*	0.4	4.0*	0.4	14.0*

* = a net loss from the site.
\+ = Concentrations of K below detectable limits at 61 cm.
\# = Concentrations of N unobtainable at 61 cm.

TABLE 4. PERCENT NUTRIENT RENOVATION OF THE MICHIGAN STUDY SITE FOR 1975-1977 GROWING SEASONS

Nutrient	1975 Mean	1976 Mean	1977 Mean
NO_3	#	76.3	85.1
Total N	#	74.0	83.7
P	94.5	98.1	98.1
K	68.1	*	65.2
Na	71.4	65.5	31.7
Ca	45.9	52.9	15.2
Mg	54.2	48.7	16.1
B	70.9	0.0	0.0
Mn	0.0	0.0	0.0
Zn	0.0	0.0	0.0

* = K levels below detectable limit at 61 cm.
\# = N levels unobtainable at 61 cm.

removal is seen to be 85.1% by 1977, while that of total N is 83.7%. These values exceed those reported by Neary (1974) on similar soils. Phosphorus removal is excellent, exceeding 94% in all three seasons. These values for NO_3 and P are similar to those reported by Leland et. al. (1978) for a non-forested old field site, underscoring the importance of grasses and associated herbs in renovating land-applied wastewater.

The amount of K, Na, Ca and Mg removed in the percolate, 16-to 65%, is less than was achieved for N and P. While these are not considered to be damaging to water quality, should they eventually enter surface waters, ammonium is potentially hazardous if oxidized to NO_2 or NO_3. It is not of major concern here, however, as only small amounts, 9.1 kg/ha in 1977, are involved. The failure of the system to remove such micronutrients as B, Mn and Zn is at this point of no major significance to water quality. However, it is uncertain what the effects may be as soil reserves of such micronutrients available to plants are further reduced.

Soil Chemistry

The highly variable nature of the soils and topography of the site precludes a detailed account of nutrient gains and losses. Preliminary trends become evident, however, when three years of data are examined for the Miami series, which extends over 75% of the study area. Figures 1-3 show soil profile data from May, 1975, near the beginning of irrigation, and October 1977, after three irrigation seasons.

Soil pH: Soil pH increased in the upper soil layers during the 3-year period. In the upper 15 cm layer pH increased from 5.3 to 7.0, while a lesser pH increase occurred in the 15-30 cm layer, from 5.9 to 6.6. Below 45 cm a soil pH decrease is indicated.

Low-to-moderate amounts of Ca, Mg, K, and Na were added to the upper soil layer. These cation bases were absorbed onto soil colloids, replacing exchangeable aluminum and hydrogen ions. This cation exchange, with subsequent formation of the hydrated hydroxyaluminum ion, is believed responsible for pH increases in the surface horizon (Tisdale and Nelson 1967). Increases in pH may continue in the upper soil layer because of the basic reaction of the effluent, pH 7.7.

Macronutrients: Total N increased by approximately 50% in the 0-15 cm, 15-30 cm, and 45-60 cm soil depths. No significant changes in total N were detected below 60 cm during the 3-year period. These amounts are below those commonly encountered in typical alfisols, 2000-4000 ppm. Changes in total N were accompanied by minor increases in NO_3 and decreases in NH_4 in the upper 15 cm soil layer. Possible mechanisms accounting for this phenomenon include (1) replacement of NH_4 in the cation exchange complex by other cations making it more susceptable to leaching loss, (2) increased NH_4 assimilation by developing tree root systems or (3) nitrification of NH_4 to NO_3 which could, in part, account for the observed soil NO_3 increases (Harmsen and Kolenbrander 1965).

Soil P levels rose 63%, from 6.7 ppm to 10.9 ppm in the upper 15 cm soil layer, and increased from 2.6 ppm to 5.9 ppm in the 15-30 cm layer. Below 30 cm the changes are not significant. Ellis (1973) reports P capacities ranging from 69 kg/ha for dune sand to 810 kg/ha for Warsaw loam. The study site is somewhat low in P and not expected to achieve its capacity in the near future. Long-term retention of P is anticipated as irrigation continues.

The profile of soil K reflects the mobility of this nutrient. Surface levels have essentially remained stable at approximately 65 ppm, while accumulations are occurring in the lower soil layers. The change at 105-120 cm is from 22 ppm to 54 ppm, a 145% increase in exchangeable K. Absorption of this ion is occurring on clay particles in the B horizon.

Sodium is increasing in all horizons as irrigation progresses. Excessive Na loading has been shown responsible for soil structure degradation in soils of finer texture (Ellis 1973). However, sodium is not expected to become a detrimental factor on this site, as these medium-textured soils are receiving abundant irrigation water to avoid a hazardous Na accumulation. Irrigation water quality was satisfactory with a sodium absorption ratio (SAR) ratio of 2.63 at an electrical conductivity of 787 umhos/cm in 1977. High Na irrigation water would have a SAR exceeding 12.0 at the observed electrical conductivity (USDA 1954).

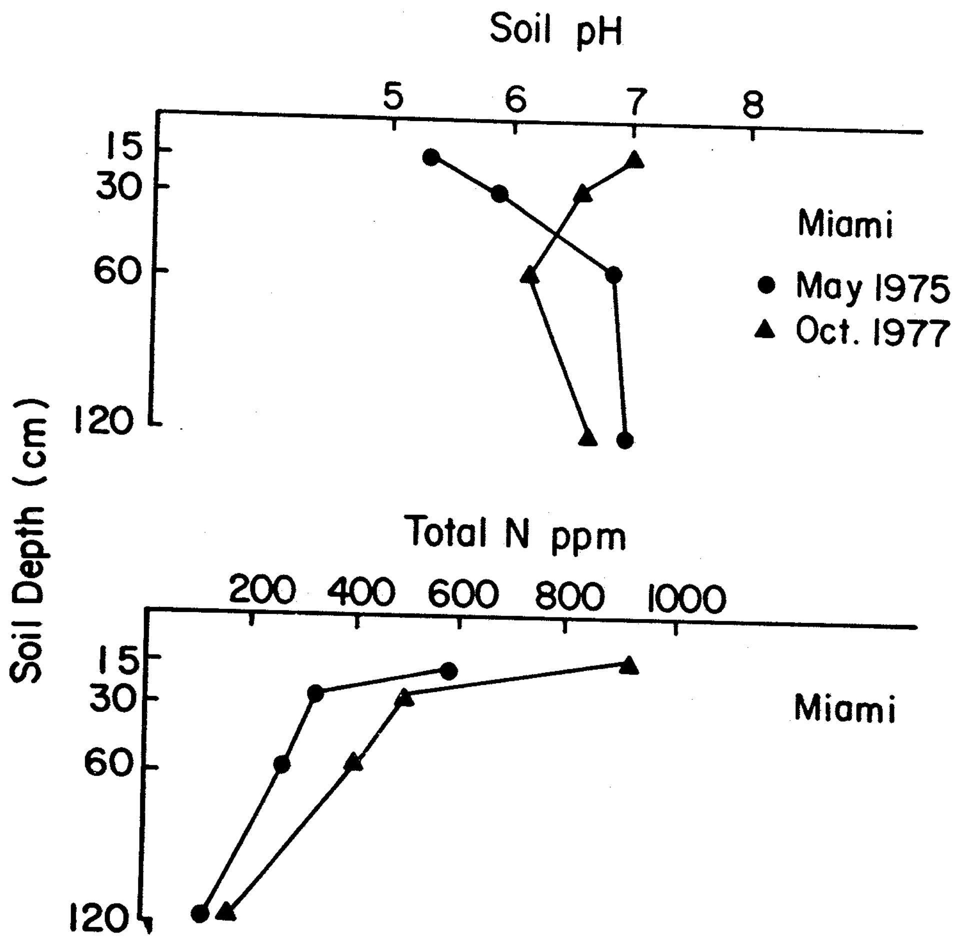

Figure 1. Soil pH and total N before (1975) and three years after (1977) wastewater irrigation.

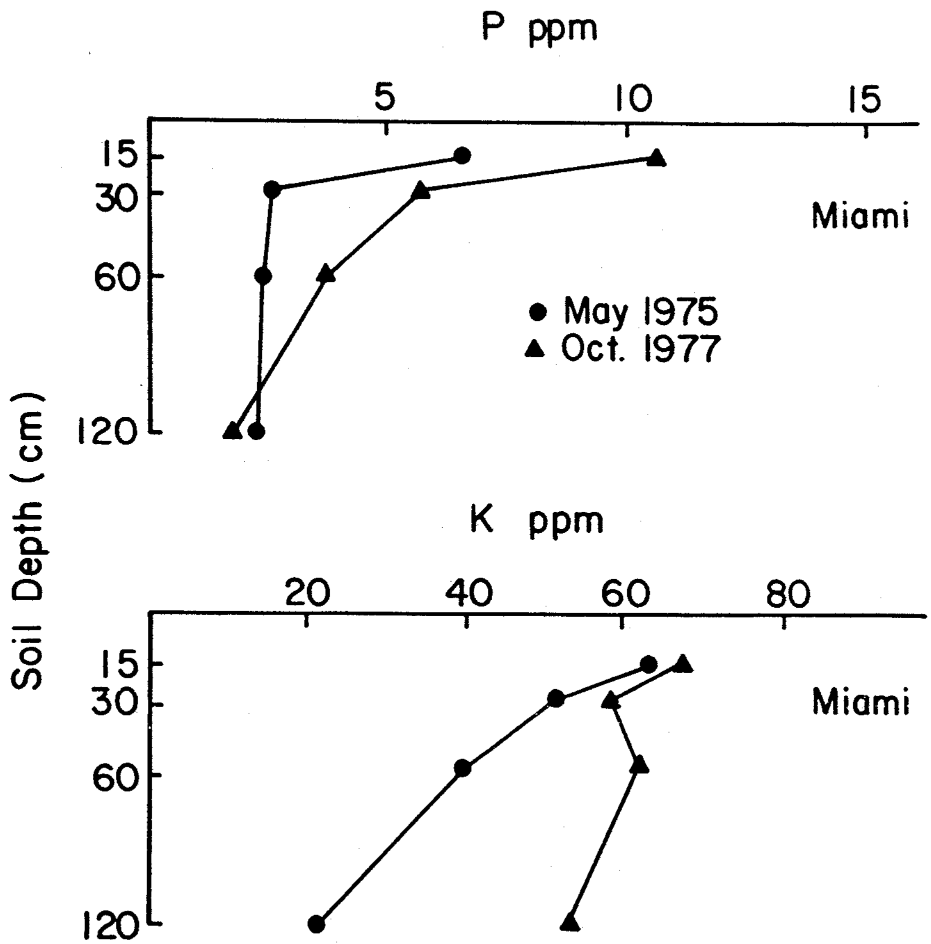

Figure 2. Soil P and K before (1975) and three years after (1977) wastewater irrigation.

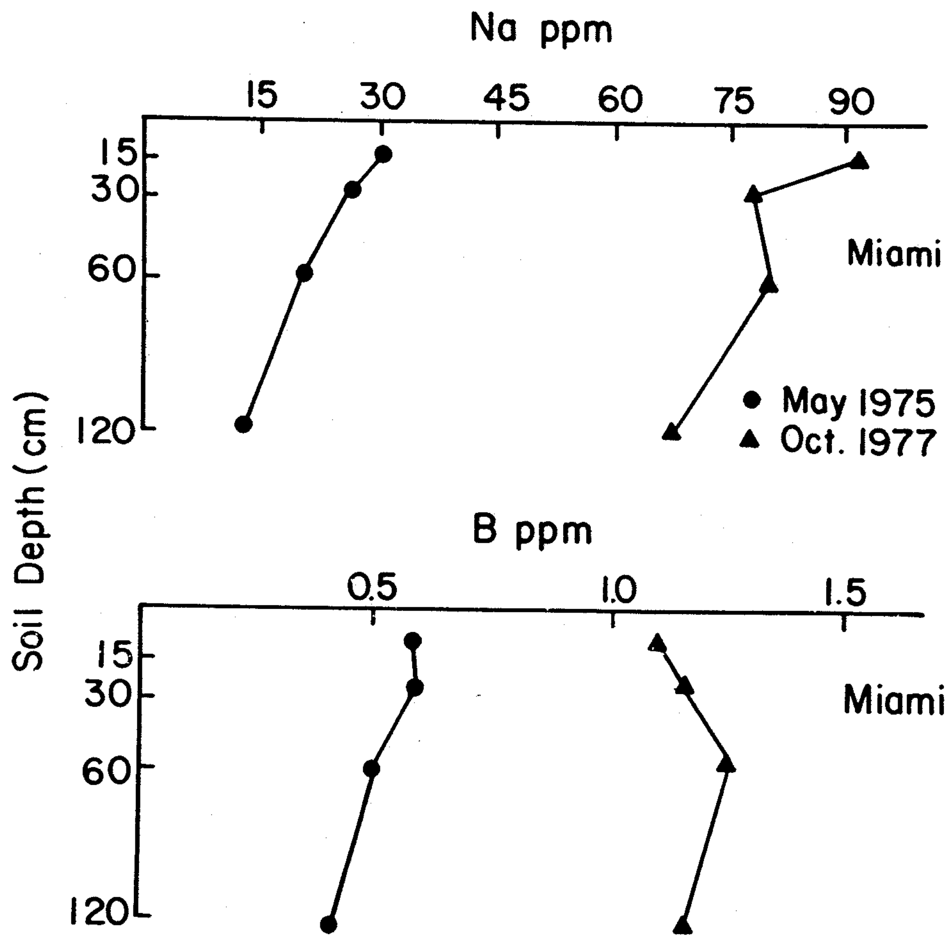

Figure 3. Soil Na and B before (1975) and three years after (1977) wastewater irrigation.

Calcium levels have remained relatively stable over the 3-year period, with 450 ppm in the surface 15 cm soil layer and nearly 130 ppm in the 105-120 cm soil layer. Levels of Mg have slowly increased from 44 ppm to 133 ppm in the uppermost 15 cm and from 89 ppm to 267 ppm in the 105-120 cm soil layer.

Micronutrients: Boron has increased from 0.5 ppm to about 1.0 ppm in all horizons. Mechanisms which could account for this include (1) B absorption from the aluminum and hydroxy compounds associated with clay particles and (2) formation of the borate diol complex with soil organic matter.

Manganese soil levels were between 8.9 and 35.5 ppm in 1977. Zinc concentrations ranged from 0.9 ppm to 2.7 ppm. Soil micronutrient levels, though low, are not deficient. Data from soil analysis indicates that micronutrient reserves are stable; however, data from soil percolate indicates extensive leaching losses. Work by Lucas and Knezek (1973) previously outlined leaching of the mobile forms of Mn and Zn under high soil moisture conditions. Work is in progress which should eventually account for these anomalies.

Tree Growth

Wastewater irrigation as a silvicultural treatment has been shown to ameliorate site conditions for plant growth (Sopper and Kardos 1973). Einspahr et al. (1972) have demonstrated that in some woody plants, height growth is stimulated primarily by applied water while diameter growth is augmented by added nutrients. Figure 4 shows the accumulated growth of plantation trees from 1974 to 1977. In four growing seasons after planting, wastewater irrigation has produced some significant growth increases over unirrigated controls (Table 5).

A comparison among the various species in this plantation showed cottonwood to be best suited to wastewater irrigation. Its response in biomass, diameter and height attainment surpassed all other species. This result was expected considering the rapid growth rate and hydrophilic nature of this species. The height growth and biomass accumulation of white ash and tulip poplar also benefited significantly from wastewater irrigation. Although Scotch pine did not express the height response exhibited by the hardwoods, biomass and diameter growth was superior to all but cottonwood. Sycamore also produced appreciable biomass, while black walnut, black cherry and Norway spruce produced but moderate growth. Red oak and white spruce were the poorest in all growth parameters measured. Species performance reported here are not unlike those cited by Smith and Evans (1977) for similar species and effluent irrigation rates.

Irrigation extends the season during which growth may occur. Flushes of growth observed in this plantation extended much later into the summer season for irrigated trees than for controls, presumably the result of favorable soil moisture conditions. Similar findings were reported by Howe (1968) in Idaho for irrigated ponderosa pine and by Kaufman (1968) for white and loblolly pines. When exposed to water stress, these pine seedlings underwent root suberization which precipitated the onset of dormancy. Where water stress was severe, the intercalary regions along each shoot also went dormant.

TABLE 5. SPECIES GROWTH RESPONSE TO WASTEWATER IRRIGATION FOLLOWING THE 1977 GROWING SEASON

Species	Height (cm)	Basal Stem Diameter (cm)	Shoot Dry wt (g)	Leaf wt/ Dry wt (%)	Stem wt/ Dry wt (%)
Cottonwood	386*	7.0*	4274*	22*	78*
Scotch Pine	134	4.5	1225	36	64
White Ash	173*	2.5	533*	28*	72*
Sycamore	174	1.9	538	38	62
Norway Spruce	87	2.0	374	34	66
Black Walnut	141	2.6	407	31	69
Tulip-poplar	145*	2.4	470*	29*	71*
Black Cherry	135	1.6	288	26	74
Red Oak	117	1.5	309	30	70
White Spruce	62	0.9	136	35	65

n = 9

* = significantly greater than control (.05 level).

A

B

Figure 4. Wastewater irrigation site in (A) 1974 and (B) 1977.

Foliar Nutrient Concentrations

Following four years of wastewater treatment, foliar nutrient levels are generally in the low-to-intermediate range of tolerable limits reported for these species (Bengston et al. 1968). By 1977, foliar N was generally in the high range, often exceeding 2% (Table 6). Irrigated trees usually contained significantly higher nutrient concentrations than unirrigated controls, an indication that the trees were assimilating the nutrients supplied in the wastewater. Nutrient dilution resulting from accelerated growth in the treated group was responsible for higher foliar nutrient concentrations in the controls. No nutrient deficiency or toxicity symptoms were detected in the plantation.

Total Nutrient Assimilation

Assessing species suitability for wastewater recycling requires evaluation of biomass production and nutrient concentrations. Leaf biomass and leaf nutrient concentrations, as an index of nutrient assimilation for the entire tree, are given in Table 7. Cottonwood and Scotch pine accumulated the greatest nutrient quantities in their foliage, followed by white ash and sycamore. These species would probably concentrate large nutrient reserves in their harvestable woody parts as well. As Kramer and Kozlowski (1960) point out, as much as 50% of the foliar content of some nutrients is retranslocated into the stem prior to leaf abscission.

In assessing the suitability of each tree species for wastewater irrigation, the following ordinal scale, based on the combined nutrient assimilation shown in Table 7 is presented.

WASTEWATER IRRIGATION SPECIES SUITABILITY

Name	Growth	Nutrient Uptake	Suitability
Cottonwood	superior	superior	superior
Scotch pine	superior	superior	superior
White Ash	good	fair	good
Sycamore	good	fair	good
Norway Spruce	fair	fair	fair
Black Walnut	fair	fair	fair
Tulip-poplar	good	poor	fair
Black Cherry	fair	poor	fair
White Spruce	poor	poor	poor
Red Oak	poor	poor	poor

TABLE 6. FOLIAR NUTRIENT CONCENTRATIONS BY SPECIES FOLLOWING WASTEWATER IRRIGATION FOR THE 1977 GROWING SEASON

Species	N C	N I	P C	P I	K C	K I	Na C	Na I	Ca C	Ca I	Mg C	Mg I	B C	B I	Mn C	Mn I	Zn C	Zn I
	%												ppm					
Cottonwood	1.9	1.9	.18	.24*	.48	0.42	.05	.19*	.78	1.12*	.14	.16	13.7	42.1*	172	185	35	36*
Scotch Pine	2.7	3.0*	.30	.32	.82	.86*	.05	.11*	2.20	1.36	.38	.40	17.4	21.1*	279	174	35	29
White Ash	2.5	2.5	.25	.26	.52	0.97*	.05	.07	.71	1.11*	.38	.36	22.0	40.1*	136	92	13	18
Sycamore	3.0	3.0	.14	.17*	1.24	1.06	.10	.12*	1.86	1.31	.19	.21*	18.3	20.8	49	44	40	32
Norway Spruce	2.0	2.6*	.40	.39	1.00	1.23*	.06	.13*	.93	.91	.40	.41	53.6	54.4	157	96	35	37
Black Walnut	2.0	2.2*	.19	.19	.66	0.52	.08	.23*	.93	1.15*	.13	.18*	28.4	54.2*	386	180	26	13
Tulip-poplar	1.8	1.8	.05	.08*	.66	0.65	.06	.13*	.61	0.81*	.15	.12	22.0	35.2	107	140	24	6
Black Cherry	2.5	2.5	.20	.19	.62	0.57	.04	.09	.66	0.55	.23	.32*	46.1	45.6	253	367	11	11
Red Oak	2.0	2.0*	.32	.22	.68	1.03*	.04	.16	.81	1.18*	.30	.23	22.0	25.9*	38	29	40	27
White Spruce	2.4	3.2*	.40	.26	.88	1.37*	.07	.36*	.86	1.27*	.50	.39	39.6	42.8	52	71	51	35

n = 9

* = Significantly Greater than Control (.05 level)

C = Control Group

I = Irrigated Group

TABLE 7. FOLIAR NUTRIENT CONCENTRATION AND CONTENT BY SPECIES AFTER 4 YEARS OF WASTEWATER IRRIGATION, 1974-1977

Species	Leaf Biomass	N		P		K		Na		Ca		Mg		B		Mn		Zn	
	(g/tree)	Conc. %	Cont. (g/tree)	Conc. %	Cont. (g/tree)	Conc. %	Cont. (g/tree)	Conc. %	Cont. (g/tree)	Conc. %	Cont. (g/tree)	Conc. %	Cont. (g/tree)	Conc. ppm	Cont. (mg/tree)	Conc. ppm	Cont. (mg/tree)	Conc. ppm	Cont. (mg/tree)
Cottonwood	940	1.9	17.9	.24	2.3	.42	3.9	.19	1.8	1.12	10.5	.16	1.5	42.1	39.6	185	173.9	36	33.8
Scotch Pine	441	3.0	13.2	.32	1.4	.86	3.8	.11	0.5	1.36	6.0	.40	1.8	21.1	9.3	174	76.7	29	12.8
White Ash	149	2.5	3.7	.26	0.4	.97	1.4	.07	0.1	1.11	1.7	.36	0.5	40.1	6.0	92	13.7	18	2.7
Sycamore	204	3.0	6.1	.17	0.3	1.06	2.2	.12	0.2	1.31	2.7	.21	0.4	20.8	4.3	44	9.0	32	6.5
Norway Spruce	127	2.6	3.3	.39	0.5	1.23	1.6	.13	0.2	.91	1.2	.41	0.5	54.4	6.9	96	12.2	37	4.7
Black Walnut	126	2.2	2.8	.19	0.2	.52	0.6	.23	0.3	1.15	1.5	.18	0.2	54.2	6.8	180	22.7	13	1.6
Tulip-poplar	136	1.8	2.5	.08	0.1	.65	0.9	.13	0.2	.81	1.1	.12	0.2	35.2	4.8	140	19.1	6	0.8
Black Cherry	75	2.5	1.9	.19	0.1	.57	0.4	.09	0.1	.55	0.4	.32	0.2	45.6	3.4	367	27.5	11	0.8
Red Oak	93	2.0	1.9	.22	0.2	1.03	1.0	.16	0.1	1.18	1.1	.23	0.2	25.9	2.4	29	2.7	27	2.5
White Spruce	48	3.2	1.5	.26	0.1	1.37	0.7	.36	0.2	1.27	0.6	.39	0.2	42.8	2.0	71	3.4	35	1.7

Cottonwood and Scotch pine are superior in overall growth and nutrient uptake resulting in the highest overall nutrient contents and superior suitability, after four seasons. White ash and sycamore, while showing good growth, experiences only fair nutrient uptake resulting in good foliar nutrient contents and good wastewater irrigation suitability.

SUMMARY

During the four years following establishment, a conifer-hardwood plantation planted on medium textured soils in Southern Michigan was irrigated with 51 mm per week of municipal wastewater. The primary goal of obtaining a continuous high quality groundwater recharge through land treatment was realized. Renovation for nitrogen approached 84% by 1977, while on-site retention of phosphorous exceeded 98% in the same year. These values are similar to those reported on non-forested old fields, underscoring the importance of grasses and associated herbs in renovating applied effluent.

Surface soil pH increased throughout the period and is expected to approach an equilibrium of 7.7 with that of the applied effluent. Levels of macronutrients progressively increased in the soil profile. Soil water data showed a decline in micronutrient reserves, a finding not evident in soil analyses. Micronutrient levels were low, but not deficient.

Cottonwood and Scotch pine benefited substantially from wastewater irrigation. These species exhibited the greatest nutrient assimilation potentials of the 10 species tested. As the stand matures and new soil equilibria develop, site utilization will become more complete. Long-term measurements of site nutrient dynamics and species productivity will be needed to choose species for the most efficient growth and nutrient assimilation when subjected to waste effluent irrigation.

LITERATURE CITED

Bengston, G. W., R. H. Brendemuehl, W. L. Pritchett and W. H. Smith (Ed.). 1968. Forest Fertilization. TVA. Muscle Shoals, Alabama, 306 pp.

Brockway, D. G., G. Schneider, and D. P. White. 1979. Dynamics of municipal wastewater renovation in a young conifer-hardwood plantation in Michigan. In: Utilization of Municipal Wastewater and Sludge on Forest and Disturbed Land. Ed. by W. E. Sopper. Pennsylvania State University Press, University Park (In press).

Burton, T. M. and J. E. Hook. 1978. Application of Municipal Wastewater to Forest Lands. In: Felton-Herron Creek, Mill Creek Pilot Watershed Studies, pp. 86-120. Ed. by T. M. Burton and T. G. Behr. Institute of Water Research, Michigan State University, East Lansing. 213 pp.

Einspahr, D. W., M. K. Benson, and M. L. Hardee. 1972. Influence of Irrigation and Fertilization on Growth and Wood Properties of Quaking Aspen, I 1-8. In: Proc Symp. Effect of Growth Acceleration on Wood. U.S.D.A., Madison. 241 pp.

Ellis, B. G. 1973. The Soil as a Chemical Filter. In: Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, pp. 46-63. Ed. by W. E. Sopper and L. T. Kardos. Pennsylvania State University Press, University Park. 462 pp.

Harmsen, G. W., and G. J. Kolenbrander. 1965. Soil Inorganic Nitrogen. pp. 43-74. In: Soil Nitrogen. Ed. by W. V. Bartholomew and F. E. Clark. Amer. Soc. of Agronomy, Madison. 603 pp.

Howe, J. P. 1968. Influence of Irrigation on Ponderosa Pine. Forest Prod. J. 18(1):84-93.

Kaufman, M. R. 1968. Water Relations of Pine Seedlings in Relation to Root and Shoot Growth. Plant Physiol. 43(2):281-288.

Kramer, P. J. and T. T. Kozlowski. 1960. Physiology of Trees. McGraw-Hill Book Co., Inc., New York. 642 pp.

Leland, D. E., D. C. Wiggert and T. M. Burton. 1978. Winter Spray Irrigation of Secondary Municipal Effluent in Michigan. In: Felton-Herron Creek, Mill Creek Pilot Watershed Studies. pp. 121-139. Ed. by T. M. Burton and T. G. Bahr. Institute of Water Research, Michigan State University, East Lansing. 213 pp..

Lucas, R. E., and B. D. Knezek. 1973. Climatic and Soil Conditions Promoting Micronutrient Deficiencies in Plants. pp. 265-282. In: Micronutrients in Agriculture. Ed. by J. J. Mortvedt, P. M. Giordano, and W. L. Lindway. Soil Sci. Soc. Am., Madison. 642 pp.

Neary, D. G. 1974. Effects of Municipal Wastewater Irrigation on Forest Sites in Southern Michigan. Ph.D. Dissertation, Michigan State University, Diss. Abst. No. 75-14949. University Microfilms, Ann Arbor.

Smith, W. H. and J. O. Evans. 1977. Special Opportunities and Problems in Using Forest Soils for Organic Waste Application. In: Soils for Management of Organic Wastes and Waste Waters. Ed. by L. F. Elliott and F. J. Stevenson. Amer. Soc. of Agronomy, Madison. pp. 429-454.

Sopper, W. E., (Ed.) 1979. Utilization of Municipal Wastewater and Sludge of Forest and Disturbed Land. Pennsylvania State University Press, University Park. (In Press).

______________, and L. T. Kardos. 1973. Vegetation Responses to Irrigation with Treated Municipal Wastewater. pp. 271-293. In: Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland, Ed. by W. E. Sopper and L. T. Kardos. Pennsylvania State University Press, University Park. 462 pp.

Thornthwaite, C. W., and J. R. Mather. 1957. Instructions and Tables for Computing Potential Evapotranspiration and Water Balance. Drexel Institute of Tech., Laboratory of Climatology 10(3):185-311.

Tisdale, S. L., and W. L. Nelson. 1967. Soil Fertility and Fertilizers. The MacMillian Company, New York. 674 pp.

U. S. Department of Agriculture, 1954. Diagnosis and Improvement of Saline and Alkaline Soils. Agriculture Handbook No. 60.

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Department of Forest and Wood Sciences
Colorado State University
Fort Collins, Colorado 80523 USA

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